E.0 Technical Approach for Siltation TMDL Devlopment

E.1 Reference Watershed Approach

TMDL development requires the identification of impairment causes and the establishment of numeric endpoints that will allow for the attainment of designated uses and water quality criteria. Numeric endpoints represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. Pennsylvania does not currently have numeric criteria for siltation. Therefore, a reference watershed approach was used to establish numeric endpoints for sediment in Wissahickon Creek. This approach is based on selecting a non-impaired watershed that shares similar land uses, ecoregions, and geomorphological characteristics with the impaired watershed. Stream conditions in the reference watershed are assumed to be representative of the conditions needed for the impaired stream to attain its designated uses. Loading rates for pollutants of concern are determined for impaired and reference watersheds through modeling studies. Both point and nonpoint sources are considered in the analysis of pollutant sources and in watershed modeling. Numeric endpoints are based on reference watershed loadings for pollutants of concern and load reductions necessary to meet these endpoints are determined. TMDL load allocation scenarios are then developed based on an analysis of the degree to which contributing sources can be reasonably reduced.

The reference watershed selection process is based on a comparison of key watershed and stream characteristics. The goal of the process is to select one or several similar, unimpaired reference watersheds that can be used to develop TMDL endpoints. Reference watershed selection was based on a desktop screening of nearby non-impaired watersheds with characteristics similar to those of the Wissahickon Creek watershed using several GIS coverages. The GIS coverages included the USGS watershed coverage, the state water plan boundaries, the satellite image-derived land cover grid (MRLC), stream reach coverage, Pennsylvania's 305(b) assessed streams database, the STATSGO soils database, and geological coverages.

Based on the aforementioned desktop GIS search for a reference watershed, the Ironworks Creek watershed, located in Bucks and Montgomery counties, was used to establish reference conditions and TMDL endpoints for the Wissahickon Creek watershed. The reference watershed was chosen based on the fact that it was an urban watershed that was not impaired by siltation and had similar physical characteristics to the Wissahickon Creek watershed (i.e., watershed size, landuse/cover, soils, geology, ecoregion). Table E-1 presents the characteristics of both the Wissahickon Creek and Ironworks Creek watersheds. Figure E-1 presents the location of the Ironworks Creek watershed.

Table E-1. Impaired and reference watershed comparison

	Wissahickon Creek	Ironworks Creek
Watershed Type	***Impaired Watershed***	***Reference Watershed***
Watershed Size (acres)	40,928	11,114
Geologic Province	Piedmont	Piedmont
Dominant Rock Types	Sandstone/Metamorphic-Igneous/Shale/Carbonate	Sandstone/Metamorphic-Igneous
Dominant Soils	C & B	C & B
Ecoregions	Triassic Lowlands Piedmont Uplands Piedmont Limestone Dolomite Lowlands	Triassic Lowlands Piedmont Uplands
Percent Slope of Watershed	0.25%	0.63%
Point Sources	0	14
Percent Urban	43%	44%
Percent Forested	40%	31%
Landuse Types:	**% Landuse**	**% Landuse**
Low Intensity Development	34.1%	39.8%
High Intensity Development	8.5%	4.2%
Hay/Pasture	7.1%	11.7%
Cropland	8.9%	10.9%
Conifer Forest	2.4%	1.8%
Mixed Forest	10.2%	10.3%
Deciduous Forest	28.0%	19.6%
Quarry	0.3%	0.0%
Coal Mine	0.02%	0.0%
Transitional	0.4%	0.1%

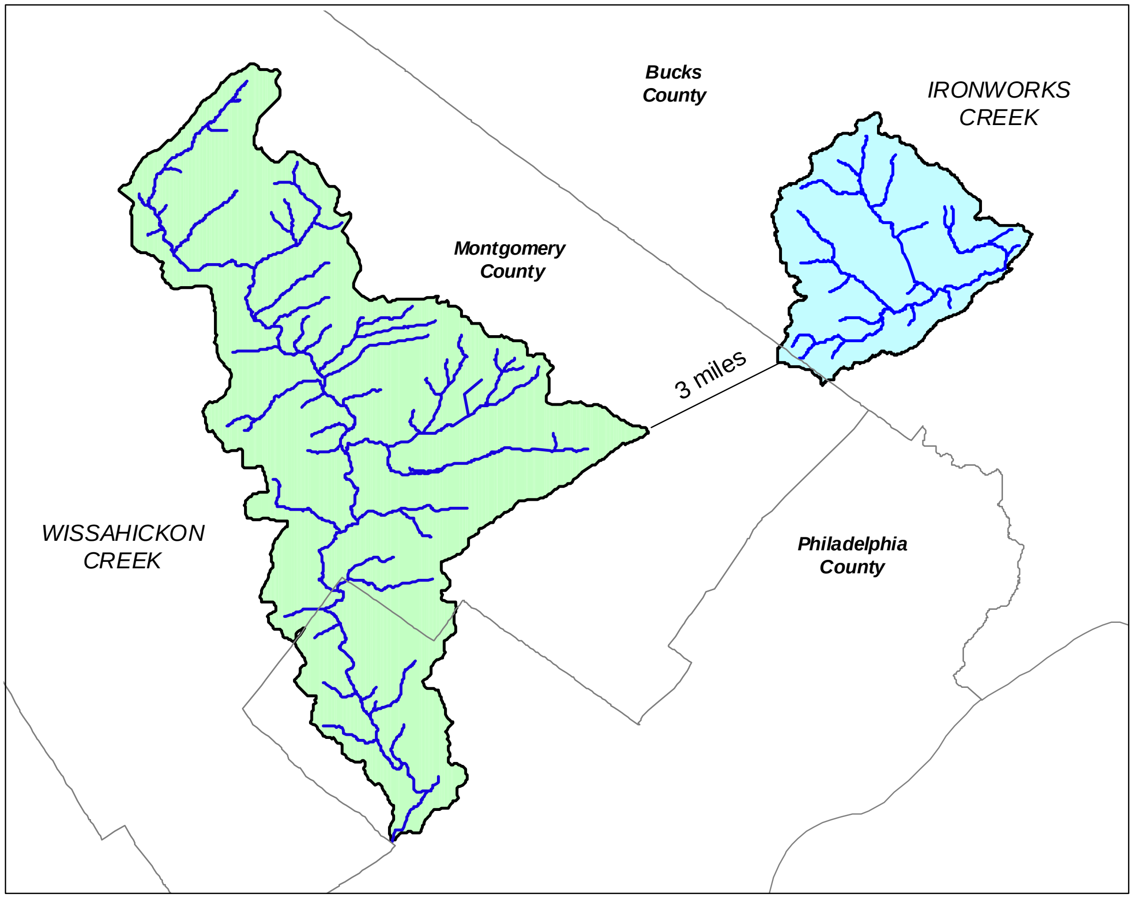

Figure E-1. Location of the reference watershed (Ironworks Creek)

Wissahickon Creek is a much larger watershed (40,928 acres) than Ironworks Creek (11,114 acres), therefore, Wissahickon Creek was delineated into five smaller watersheds that could easily be compared to Ironworks Creek (Figure E-2). Ironworks Creek was subsequently re-delineated to appropriately match each of the five subwatersheds in the Wissahickon Creek watershed.

To equate target and reference watershed areas for TMDL development, the total area for the reference watershed was adjusted to be equal to the area of its paired target watershed, after hydrology calibration. To accomplish this, land use areas (in the reference watershed) were proportionally adjusted based on the percent land use distribution. As a result, the total watershed area for Ironworks Creek was adjusted to be equal to the five modeled subwatersheds in Wissahickon Creek, respectively.

E.2 Overall Technical Approach

A reference watershed approach (see section E.1) was used in this study to develop siltation TMDLs for the Wissahickon Creek watershed. A watershed model was used to simulate sediment loads from potential sources in the impaired and reference watersheds. The watershed model used in this study was the Generalized Watershed Loading Functions (GWLF) model (Haith and Shoemaker 1987). GWLF modeling was accomplished using the AVGWLF watershed simulation program, which includes a GIS interface developed by the Environmental Resources Research Institute of the Pennsylvania State University (details in Section X.3). Numeric endpoints were based on the unit-area loading rates that were calculated for the reference watersheds. TMDLs were then developed for each impaired stream segment based these endpoints and the results from load allocation scenarios.

E.3 Watershed Model

The TMDLs were developed using the GWLF model. The GWLF model, which was originally developed by Cornell University (Haith and Shoemaker, 1987; Haith et al., 1992), provides the ability to simulate runoff, sediment, and nutrient loadings from watersheds given variable-size source areas (e.g., agricultural, forested, and developed land). It is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment loads, based on the daily water balance accumulated to monthly values.

GWLF is an aggregated distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios. Each area is assumed to be homogenous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover/soil type combination). The KLSCP factors are variables used in the calculations to depict changes in soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P). A sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff are applied to the calculated erosion to determine sediment yield for each source area. Evapotranspiration is determined using daily weather data and a cover factor dependent on land use/cover type. Finally, a water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. All of the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker, 1987) and GWLF User's Manual (Haith et. al, 1992).

In addition to the model functions described above, a streambank erosion routine was also used to determine the total sediment load to the watershed. The streambank erosion routine is based on an approach in which monthly streambank erosion is estimated by calculating a watershed-specific lateral erosion rate (LER) for streams in the watershed. The total sediment load in the watershed generated by streambank erosion is calculated by multiplying the LER by the total length of streams in the watershed, the average streambank height, and the average soil bulk density. For a more detailed discussion of the streambank erosion algorithm, see the AVGWLF Version 4.0 User's Guide (Evans et al. 2001).

Sediment point sources were not included in the GWLF model because GWLF is set up to include nutrient point sources, but not sediment point sources. There are 14 point sources of sediment in the Wissahickon Creek watershed (see Section 2.2.2). The sediment loads (in lbs/yr) from these point sources were calculated outside of the model based on their permitted flow and TSS concentration. The sediment delivery ration for the watershed in which each point source was located was applied to the total sediment load from that point source to determine the resulting sediment load at the mouth of the watershed after transport losses.

For execution, the model requires separate input files containing transport- and weather-related data. The transport file (TRANSPRT.DAT) defines the necessary parameters for each source area to be considered (e.g., area size, curve number) as well as global parameters (e.g., initial storage, sediment delivery ratio) that apply to all source areas. The weather file (WEATHER .DAT) contains daily average temperature and total precipitation values for each year simulated.

1.3.1 GIS-Based Derivation of Input Data for the Watershed Model

The primary sources of data for the TMDL analyses were GIS formatted databases. A specially designed interface, ArcView Version of the Generalized Watershed Loading Function (AVGWLF), was prepared by the Environmental Resources Research Institute of the Pennsylvania State University in ArcView (GIS software) to generate the data needed to run the GWLF model (Evans and Lehning, 2000; Evans et al., 2000).

In using the AVGWLF interface, the user is prompted to identify required GIS files and to provide other information related to "nonspatial" model parameters (e.g., beginning and end of the growing season, beginning and end date of available weather data). This information is subsequently used to automatically derive values for required model input parameters, which are then written to the TRANSPRT.DAT and WEATHER.DAT input files needed to execute the GWLF model. For use in Pennsylvania, AVGWLF has been linked with statewide GIS data layers such as land use/cover, soils, topography, and physiography, and it includes location-specific default information such as and cropping practices. Complete GWLF-formatted weather files also are prepared for 88 weather stations around the state.

Table E-2 lists the GIS data sets and provides an explanation of how they were used for development of the input files for the GWLF model.

Table E-2. Statewide GIS data sets (Source: Evans and Lehning, 2000; Evans et al., 2000)

County	The county boundaries coverage lists data on conservation practices that provide C and P values for the Universal Soil Loss Equation (USLE)
Landuse5	Grid of the Multi-Resolution Land Characteristics (MRLC, 1991-1993) that has been reclassified into five categories. This is used primarily as background.
Majroad	Coverage of major roads. Used for reconnaissance of a watershed.
MCD	Minor civil dividions (boroughs, toenships, and cities)
NPDES	A coverage of permitted point sources. Provides background information and cross check for the point source coverage.
PADEM	100-meter digital elevation model. This is used to calculate landslope and slope length.
PALUMRLC	A satellite image-derived land cover grid (MRLC) that is classified into 15 different land cover categories. This data set provides land cover loading rates for the different categories in the model.
Pasingle	The 1:24,000 scale single-line stream coverage of Pennsylvania. Provides a complete network of streams with coded stream segments.
Physprov	A shapefile of physiographic provinces. Attributes *rain_cool* and *rain_warm* are used to set rainfall erosivity, and *gwrecess* is used to set recession coefficients.
Pointsrc	Major point source discharges with permitted nitrogen and phosphorus loads.

Smallsheds	A coverage of small watersheds for named streams at the 1:24,000 scale. This coverage is used with the stream network to delineate the desired watershed level.
STATSGO	A shape file of generalized soil boundaries. The attribute *mu_k* sets the k factor in the USLE. The attribute *mu_awc* is the unsaturated available capacity, and the *muhsg_dom* is used with land use/cover to derive curve numbers.
Strm305	A coverage of stream water quality as reported in Pennsylvania's 305(b) report. Current status of assessed streams.
Surfgeol	A shapefile of the surface geology used to compare watersheds with similar qualities.
Zipcode	A coverage of animal densities. Attribute *aeu_acre* helps estimate nitrogen and phosphorus concentrations in runoff in agricultural lands and over manured areas.
Weather Files	Historical weather files for stations around Pennsylvania to simulate flow.

As described in the Watershed Model section (E.3), the GWLF model provides the ability to simulate surface water runoff, as well as sediment loads, from a watershed based on landscape conditions such as topography, land use/cover, and soil type. In essence, the model is used to estimate surface runoff and nonpoint source loads from different areas in the watershed.

E.3.2 Explanation of Important Model Parameters

In the GWLF model, the nonpoint source load calculated is affected by terrain conditions such as amount of agricultural land, land slope, and inherent soil erodibility. It also is affected by farming practices used in the area, as well as by background concentrations of nutrients (nitrogen and phosphorus) in soil and groundwater. Various parameters are included in the model to account for these conditions and practices. Some of the more important parameters are summarized below:

Areal extent of different land use/cover categories: This parameter is calculated directly from a GIS layer of land use/cover.

Curve number: This parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use/cover and hydrologic soil type and is calculated directly using digital land use/cover and soils layers.

K factor: This factor relates to inherent soil erodibility, and it affects the amount of soil erosion taking place on a given unit of land.

LS factor: This factor signifies the steepness and length of slopes in an area and directly affects the amount of soil erosion.

C factor: This factor is related to the amount of vegetative cover in an area. In agricultural areas, this factor is largely controlled by the crops grown and the cultivation practices used. Values range from 0 to 1.0, with larger values indicating greater potential for erosion.

P factor: This factor is directly related to the conservation practices used in agricultural areas. Values range from 0 to 1.0, with larger values indicating greater potential for erosion.

Sediment delivery ratio: This parameter specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size.

Unsaturated available water-holding capacity: This parameter relates to the amount of water that can be stored in the soil and affects runoff and infiltration. It is calculated using a digital soils layer.

More detailed information about the parameters and outlined above can be obtained from the GWLF User's Manual (Haith et al., 1992). Specific details in the manual that describe equations and typical parameter values used can be found on pages 15 through 41.

E.3.3 Meteorological Data

Local rainfall and temperature data were used to simulate flow conditions in modeled watersheds. Hourly precipitation and daily temperature data were obtained from local National Climatic Data Center (NCDC) weather stations and other sources. Daily maximum and minimum temperature values were converted into daily averages for modeling purposes. The period of record selected for model runs (April 1, 1993 through March 31, 2001) was based on the availability of recent weather data and corresponding streamflow records. The weather data collected at the NCDC station of Palm 3 SE were used to construct the weather file used in all watershed simulations (both impaired and reference). Figure E-3 shows the location of the weather station used for modeling purposes.

E.3.4 Hydrology Calibration

Daily streamflow data are needed to calibrate watershed hydrology parameters in the GWLF model. There is a continuous USGS flow gage at the mouth of Wissahickon Creek (USGS 0147400 Wissahickon Creek at mouth, Philadelphia, PA) that has flow data from October 1, 1965 through September 30, 2001. There is no flow gage in the reference watershed of Ironworks Creek, so hydrology was calibrated at the nearby Little Neshaminy Creek watershed, which is similar in size as well as other characteristics (i.e., soils, geology, landuse) to Ironworks Creek. The Little Neshaminy gage (USGS 01464907 Little Neshaminy Creek @ Valley Rd near Neshaminy, PA) has flow data from November 25, 1998 through September 30, 2001.

Using the input files created in AVGWLF, the model predicted overall water balances in impaired and reference watersheds. For both Wissahickon Creek and Ironworks Creek, weather data obtained from the NCDC meteorological station located at Palm 3 SE were used to model the chosen time period (April 1, 1993 through March 31, 2001 for Wissahickon Creek and April 1998 through March 2001 for Ironworks Creek). The modeling period is determined based on the availability of weather and flow data that were collected during the same time period. In general, an R^2 value greater than 0.7 indicates a strong, positive correlation between simulated and observed data. The R^2 value for the Wissahickon Creek and ironworks Creek hydrology calibrations were 0.76 and 0.74, respectively. These results indicate a good correlation between simulated and observed results for these watersheds. Hydrology calibration results and the modeled time period for reference watersheds are presented in Figures E-4 and E-5.

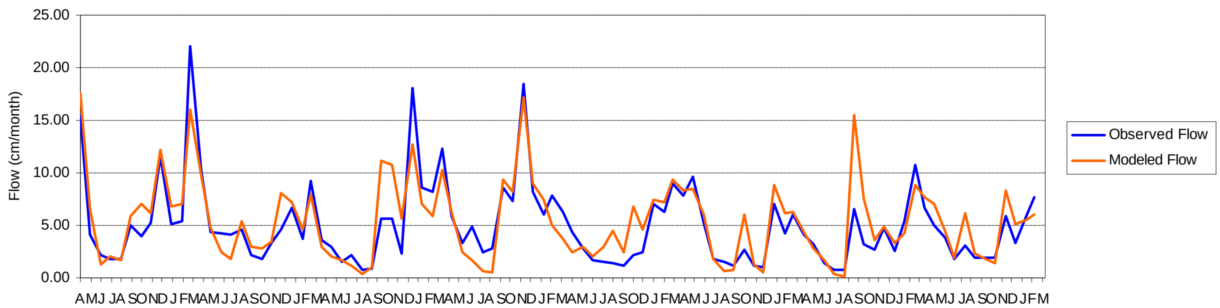

Figure E-4. Hydrology calibration at USGS gage 01474000 (Wissahickon Creek at Mouth, Philadelphia, PA); April 1993 through March 2001

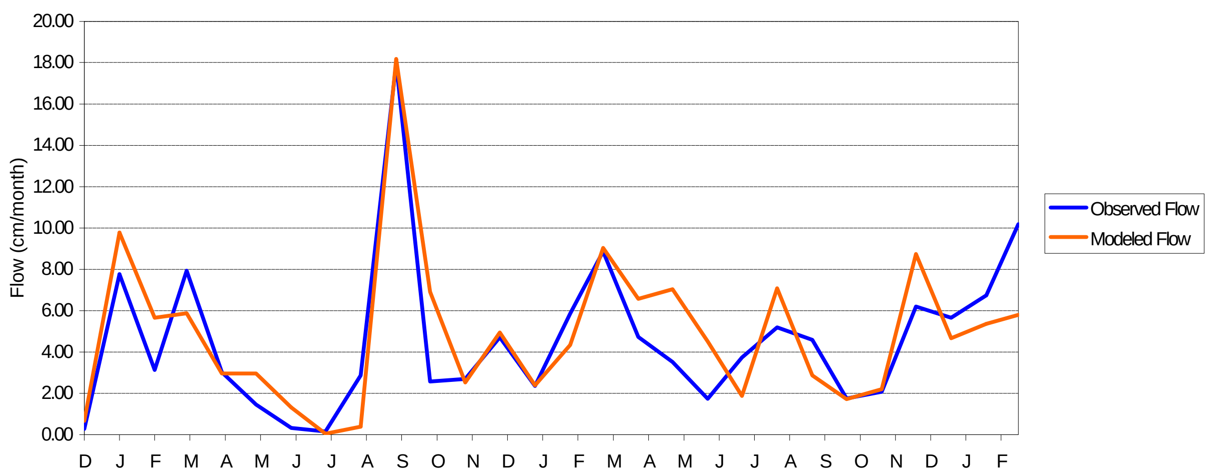

Figure E-5. Calibration for Ironworks Creek using the reference gage at Little Neshaminy Creek (USGS 01464907). December 1998 through March 2001.

E.3.5 Water Quality Calibration

Water quality observations at the same location as USGS gage 01474000 at the mouth of Wissahickon Creek were available (as a concentration) to compare to model output, however, sediment loading rates are predicted by GWLF as monthly loads. The average daily streamflow and monthly TSS concentrations in mg/L were used to determine an estimated monthly sediment load based on linear regression. Based on the comparison of the model output to observed TSS values for the period of January 1994 through December 2000, the Wissahickon Creek watershed's C (vegetation cover) and P (conservation practices) values were adjusted to reflect the high sediment loads observed in the watershed. Observed water quality data were not available for comparison to reference watershed output, therefore the default sediment parameters selected during GWLF setup were used. Based on habitat assessments provided by PADEP for waterbodies in the Wissahickon Creek watershed as well as the Ironworks Creek watershed, the Wissahickon Creek watershed had poorer habitat conditions than Ironworks creek, which supports the increased C and P values used in modeling the Wissahickon Creek watershed. Figure E-6 presents the observed monthly sediment load in Wissahickon Creek (based on the monthly observed concentrations and daily flow values) compared to sediment output from the GWLF model.

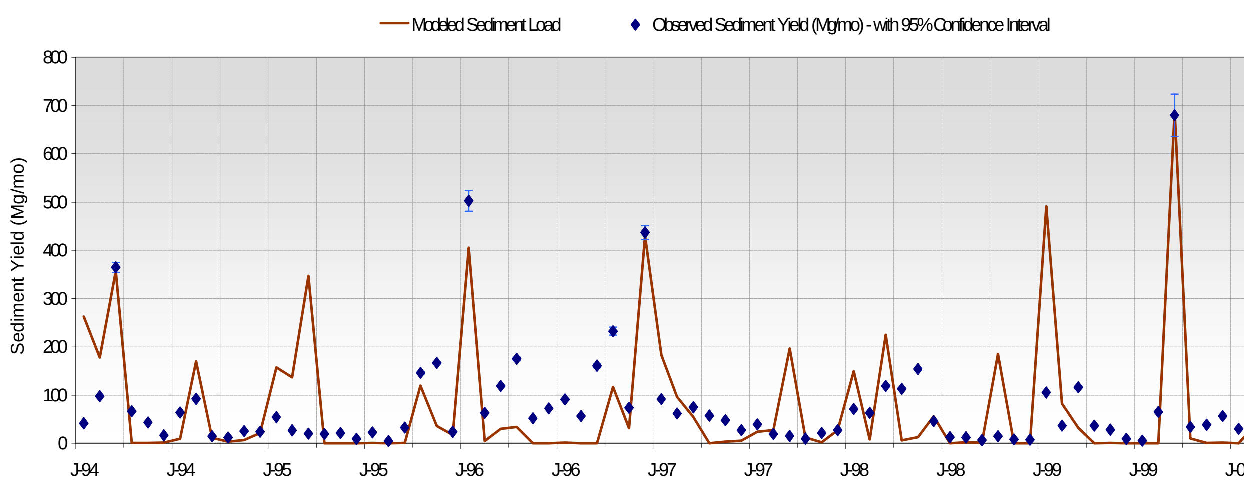

Figure E-6. Observed sediment compared to GWLF modeled sediment loads at USGS 0147400 at the mouth of Wissahickon Creek